Comparative techno-economic assessment of low-CO_2 hydrogen production technologies

Stefania Osk Gardarsdottir, Mari Voldsund, Simon Roussanaly

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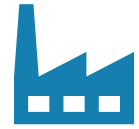
System boundaries and cases

H_2 production	H_2 conditioning	Transport	Delivery and end-use
NG reforming + CCS	Liquefaction 	Ship 	Power plants 
Electrolysis	Compression 	Pipeline 	FCVs 

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Key performance indicators (KPIs)

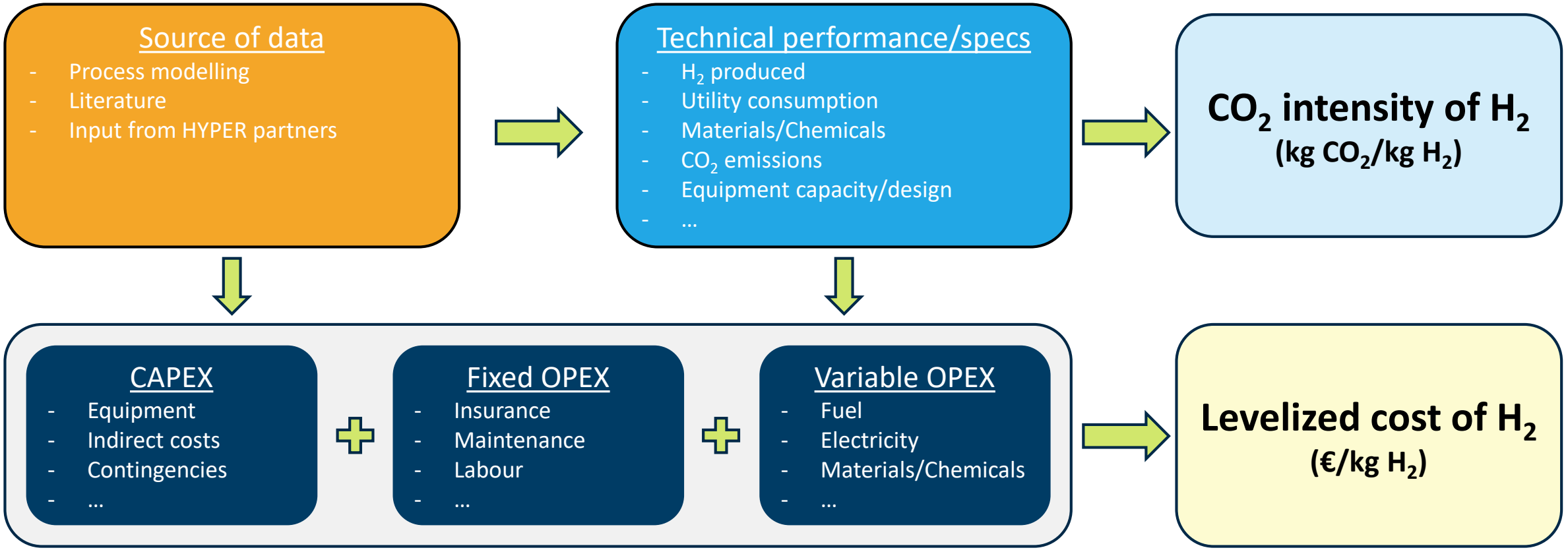
Levelized cost of H_2

$$C_{H_2} = \frac{\sum_{t=1}^{n}(CAPEX_t + OPEX_t)(1+r)^{-t}}{\sum_{t=1}^{n} P_{H_2}(1+r)^{-t}} \qquad [€/kg_{H2}]$$

CO_2 intensity of H_2

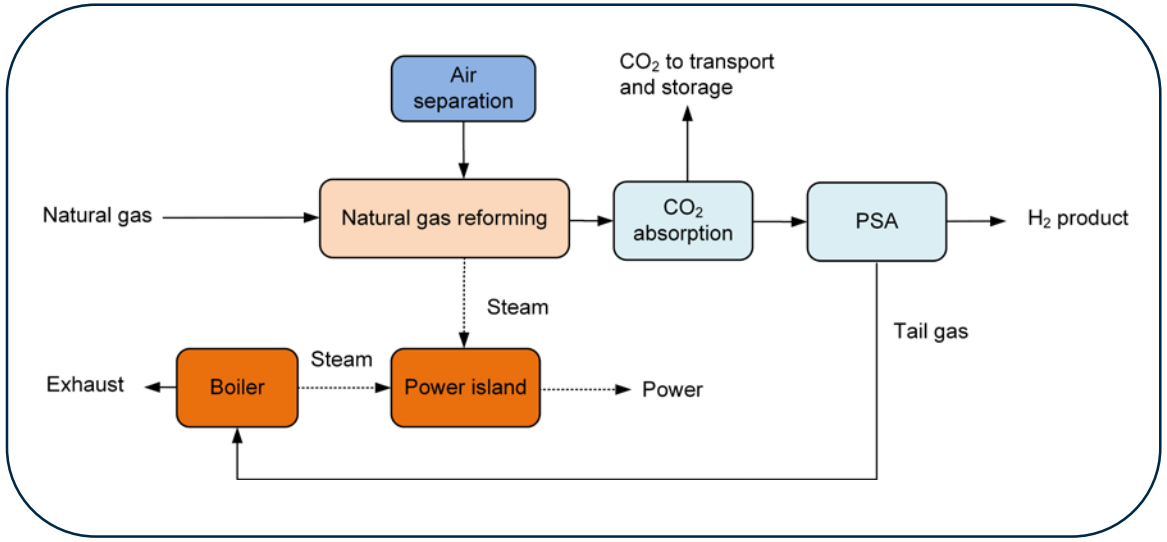
$$e_{H_2} = \frac{m_{CO_2} + P_{el} \cdot e_{el} + m_{NG} \cdot e_{NG}}{m_{H_2}} \qquad [kg_{CO2}/kg_{H2}]$$

Methodology overview

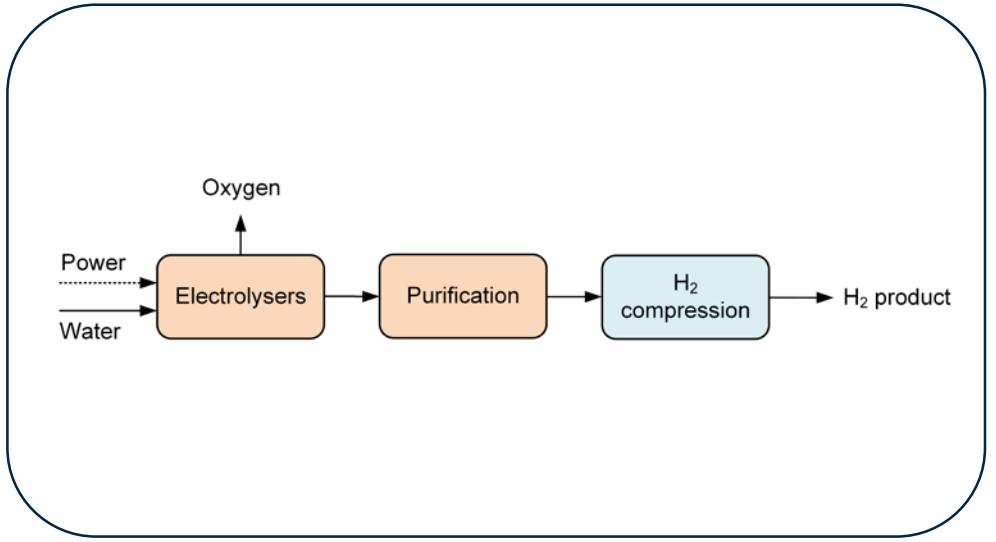


H_2 production methods

NG reforming with CO_2 capture



Electrolysis



Product specifications:

- 99.999 % H_2
- Min 20 bar

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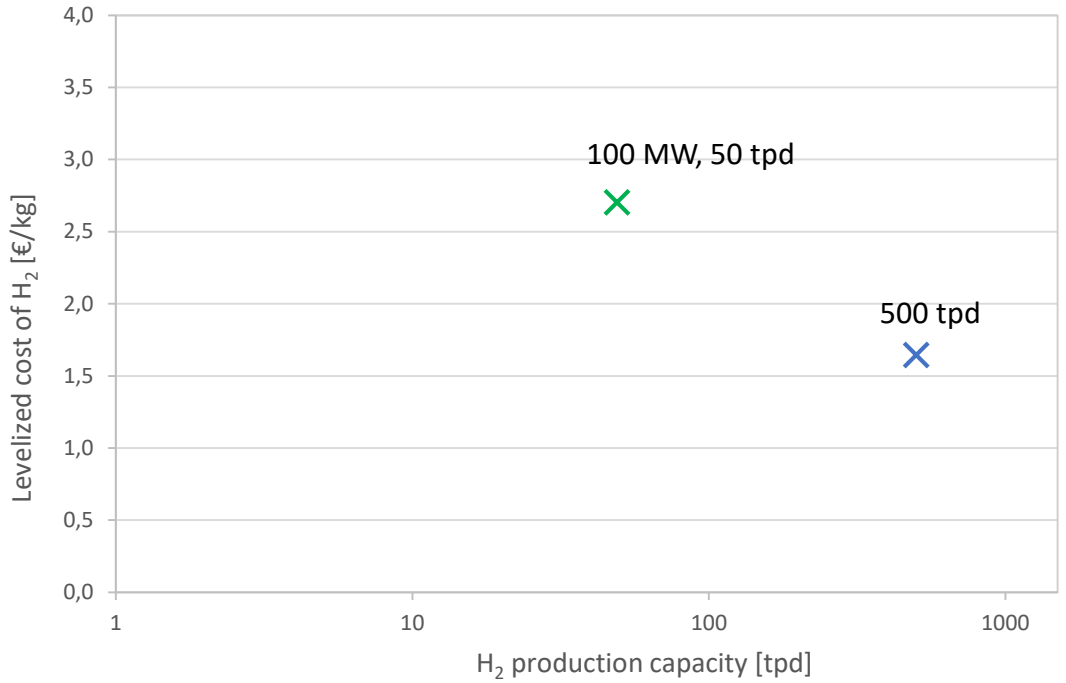
Levelized cost of H_2



Important assumptions:

- Electricity 38 €/MWh
- Natural gas 4.5 €/GJ
- Utilization factor 95%
- Lifetime 25 years

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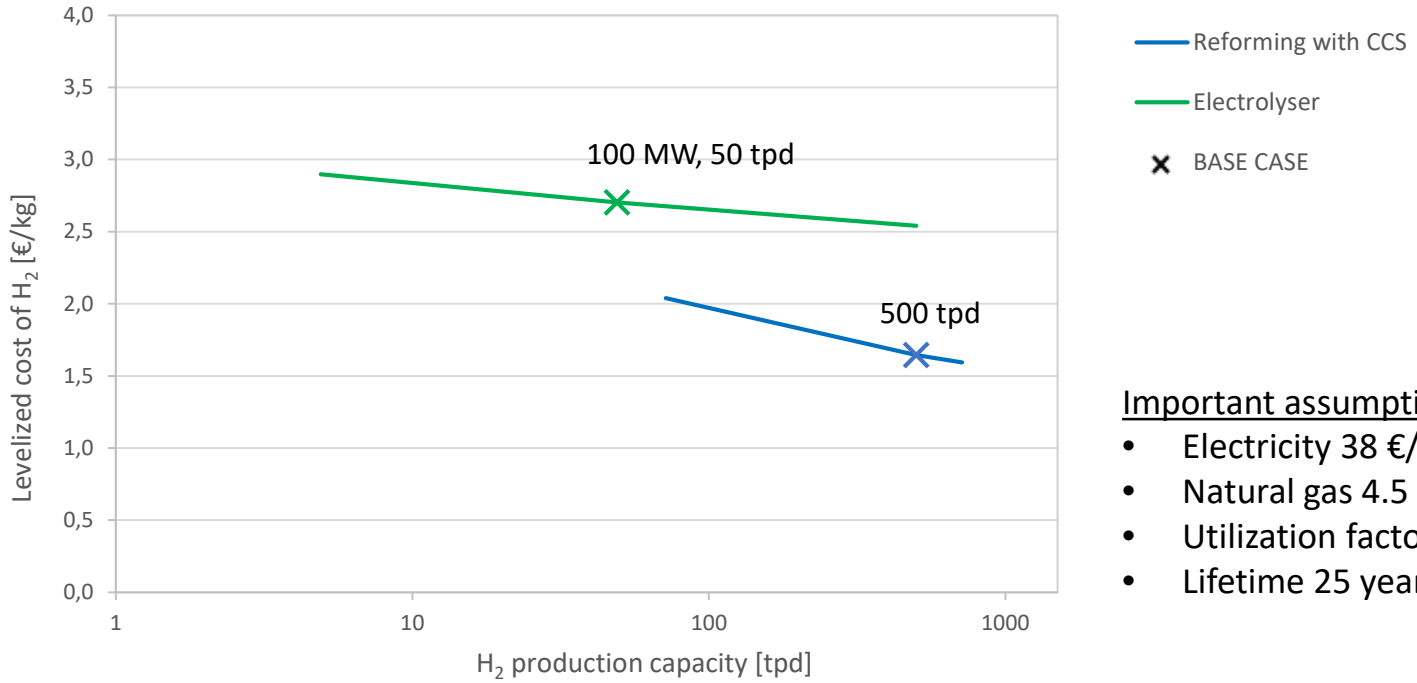
Levelized cost of H_2



Important assumptions:

- Electricity 38 €/MWh
- Natural gas 4.5 €/GJ
- Utilization factor 95%
- Lifetime 25 years

- Reforming with CCS most economic for large scale H_2 production

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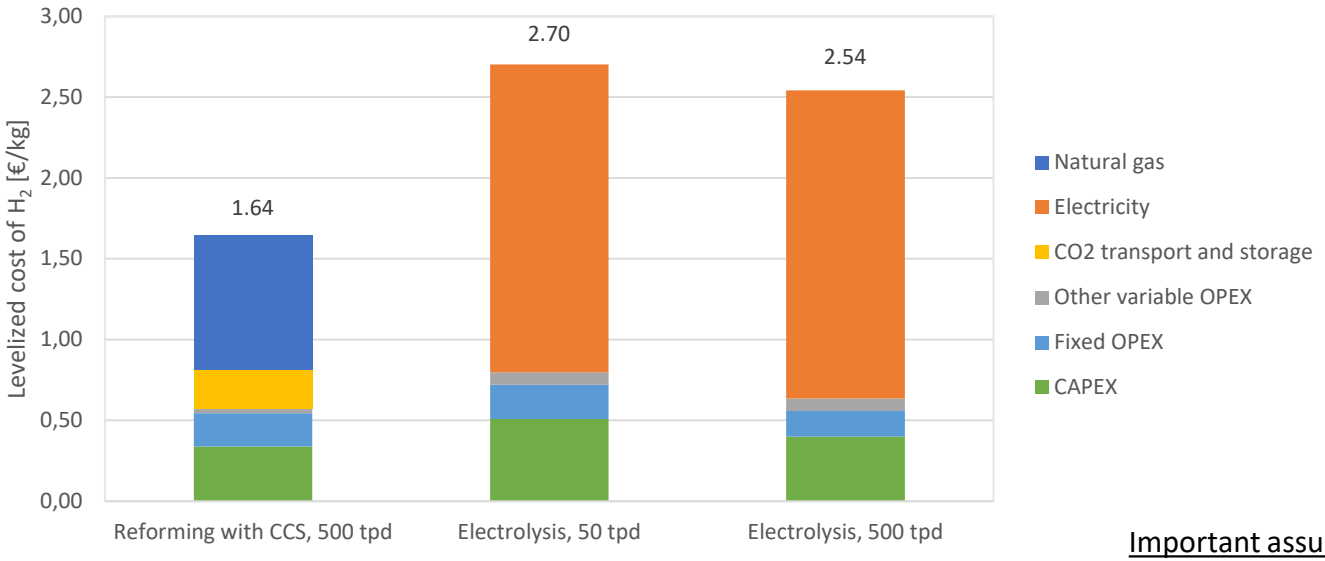
Breakdown of costs



- Variable operating costs most important cost element for both technologies

Important assumptions:

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- Natural gas 4.5 €/GJ
- Utilization factor 95%
- Lifetime 25 years

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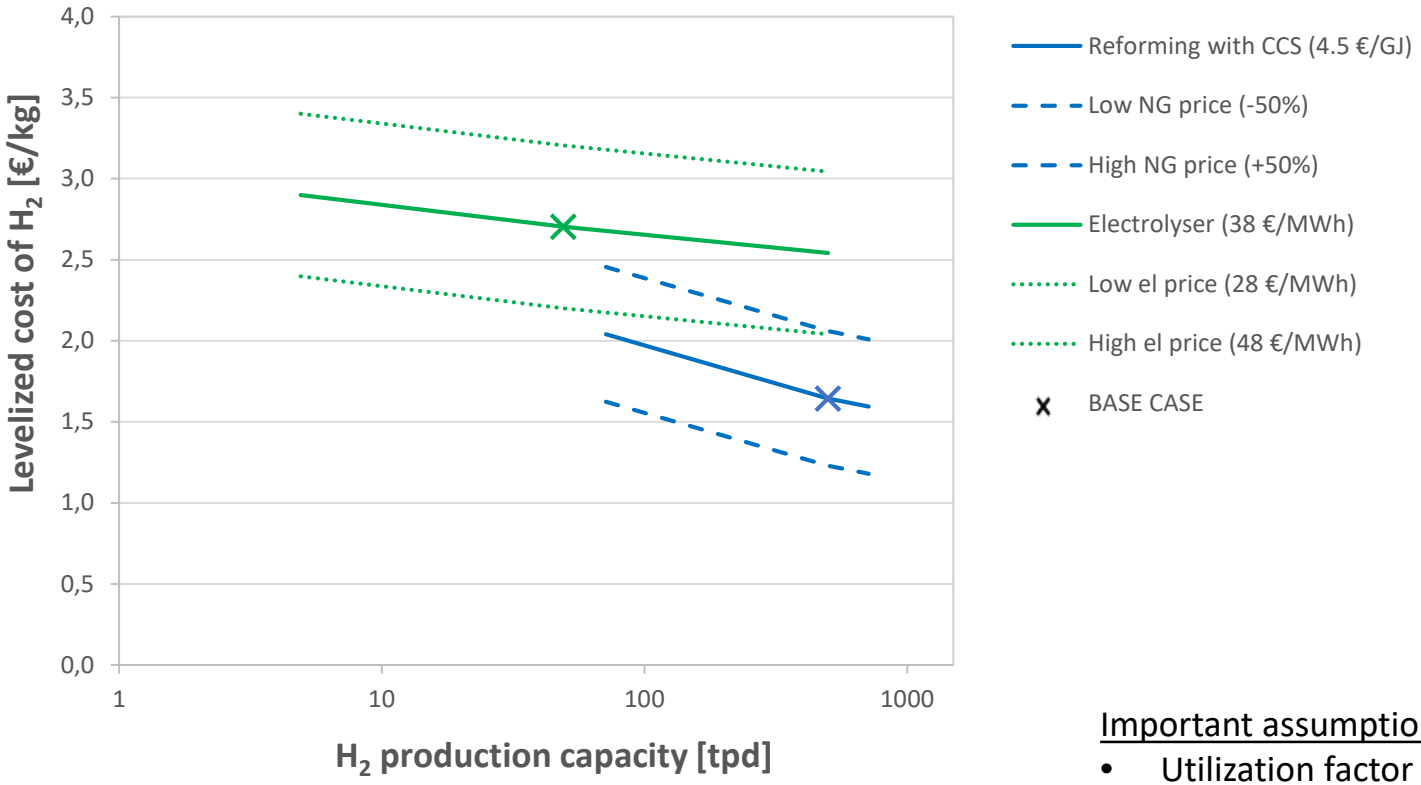
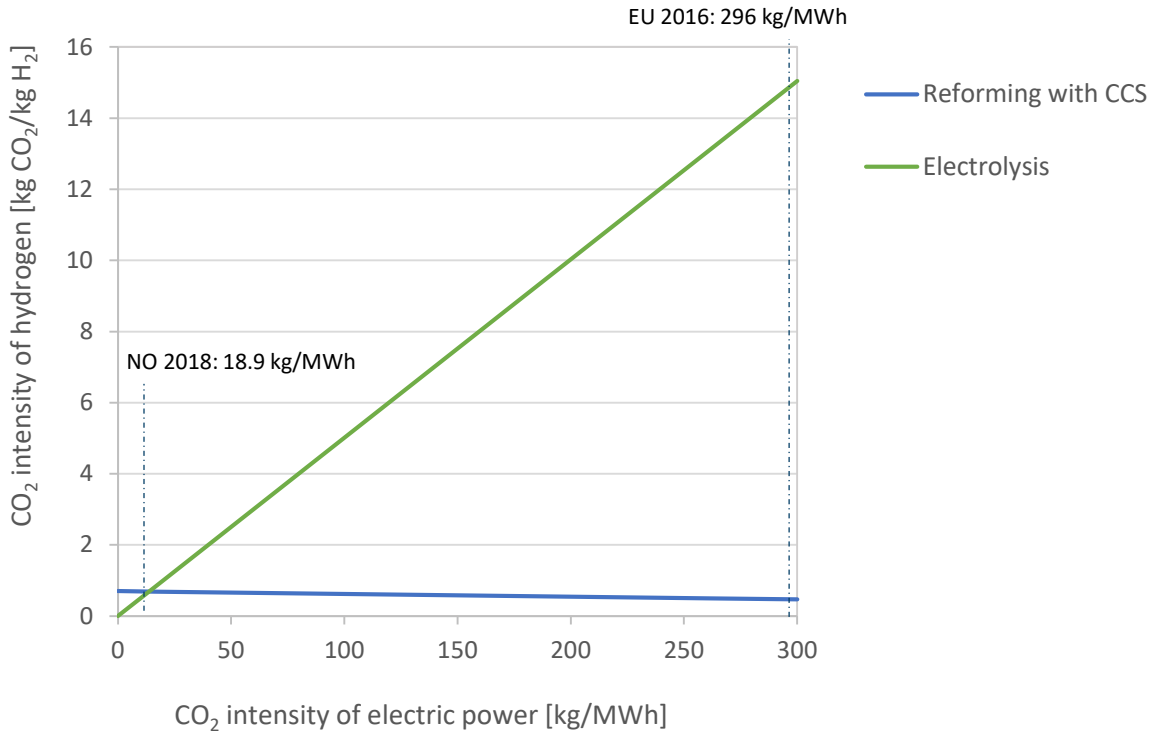
Influence of electricity and gas prices



Important assumptions:

- Utilization factor 95%
- Lifetime 25 years

Influence of CO_2 intensity of electricity



- CO_2 intensity of H_2 produced by NG reforming with CCS and electrolysis is the same at a grid CO_2 intensity of ~20 kg/MWh

- H_2 production via electrolysis must thus guaranty that, at least, 94.8% of its consumed power comes from renewables to be more climate-friendly than the NG reforming with CCS route

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Technology comparison

	Advantages	Limitations
Natural gas reforming with CCS	• Maturity in large-scale applications • Low power demand • Low cost for large scale • Low product CO_2-intensity independent of electricity system	• Less flexible • Fossil based feedstock • Conventional technology is less suitable for small-scale applications
Electrolysis	• Modular technology • No direct fossil fuel input • Suitable for flexible operation	• Product CO_2-intensity highly sensitive to electricity system CO_2 intensity • (Very) large-scale experience lacking • Grid considerations for large plants • Relatively high cost

Concluding remarks

- NG reforming with CCS outperforms electrolysis for large-scale production
- For small scale production, electrolysis might be a more attractive option
- CO_2-footprint of H_2 from NG reforming with CCS and from electrolysis is at a similar level (0.7-1 kg CO_2/kg H2) when electricity is supplied by the Norwegian electricity system
  - At least 94.8% of the consumed power in H_2 production with electrolysis must come from renewables to be more climate-friendly than the NG reforming with CCS route

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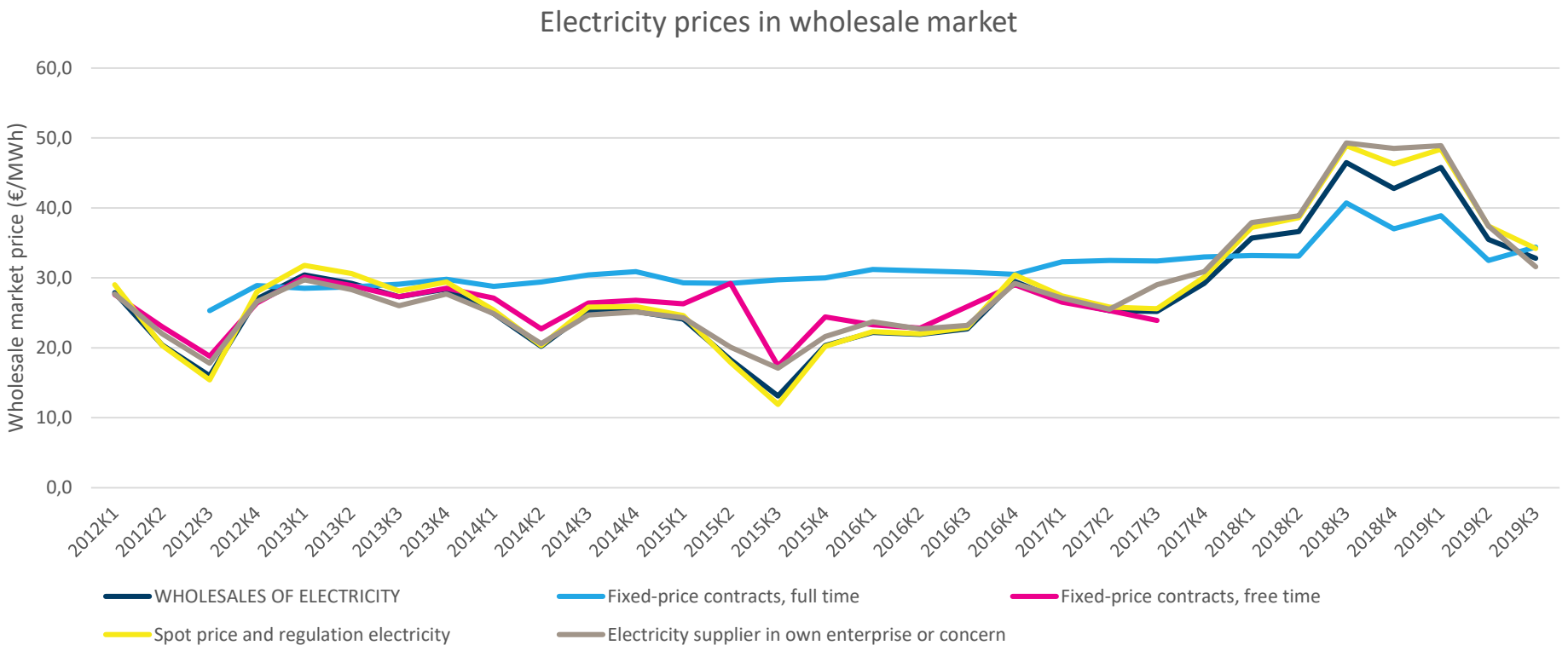
EXTRAS

Electricity prices in Norway



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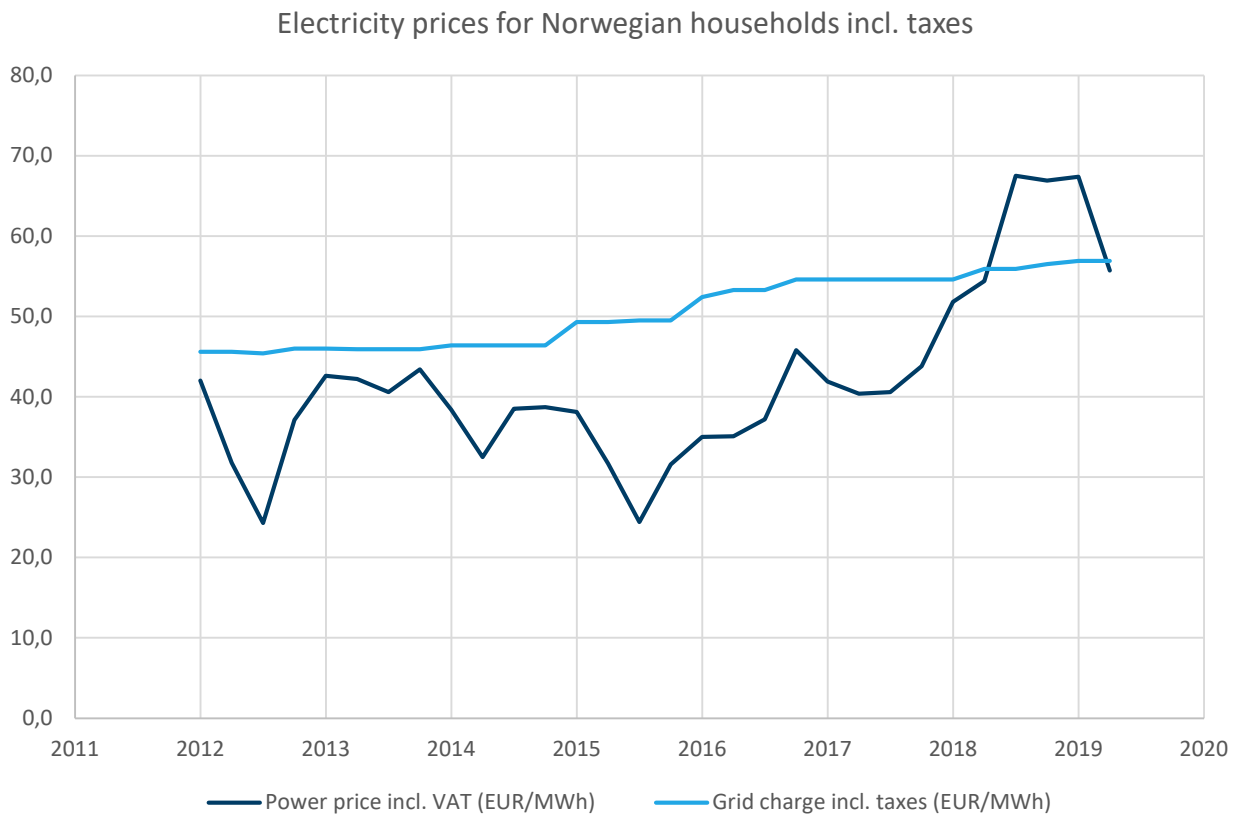
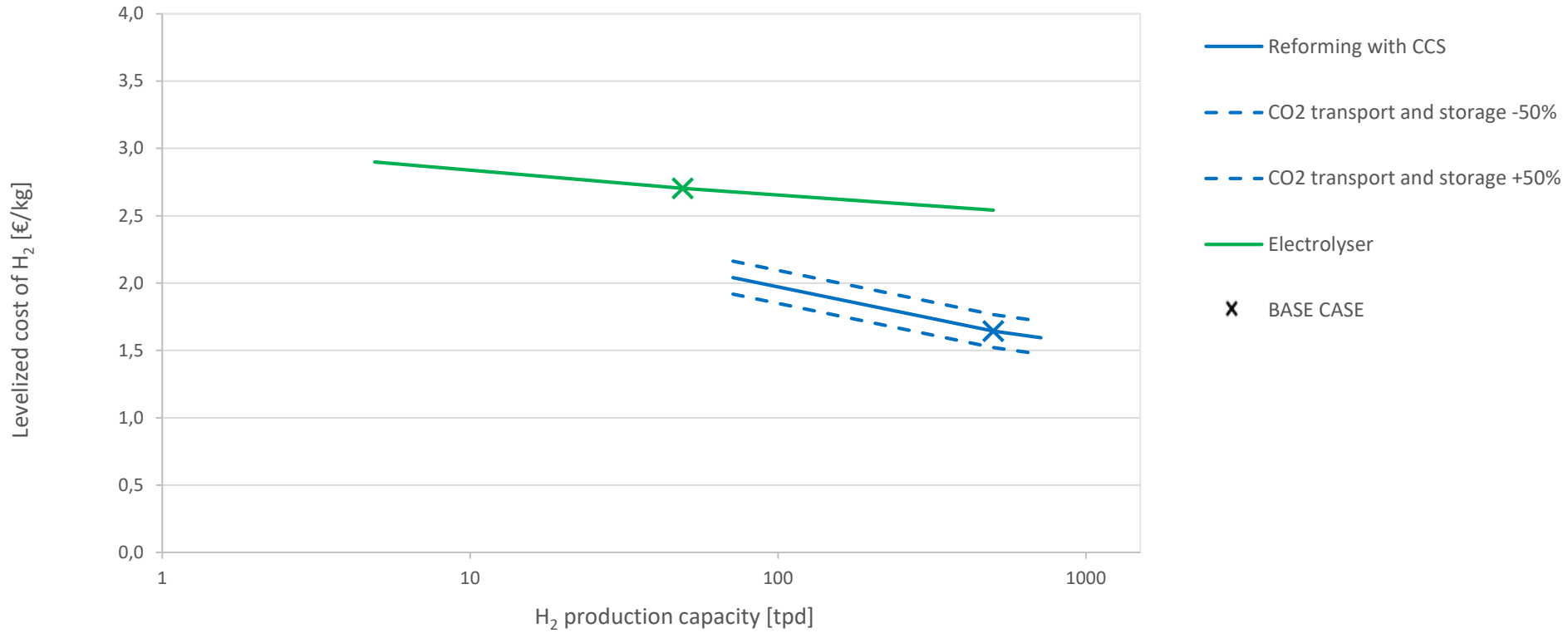
Electricity prices in Norway



Influence of CO_2 transport and storage cost



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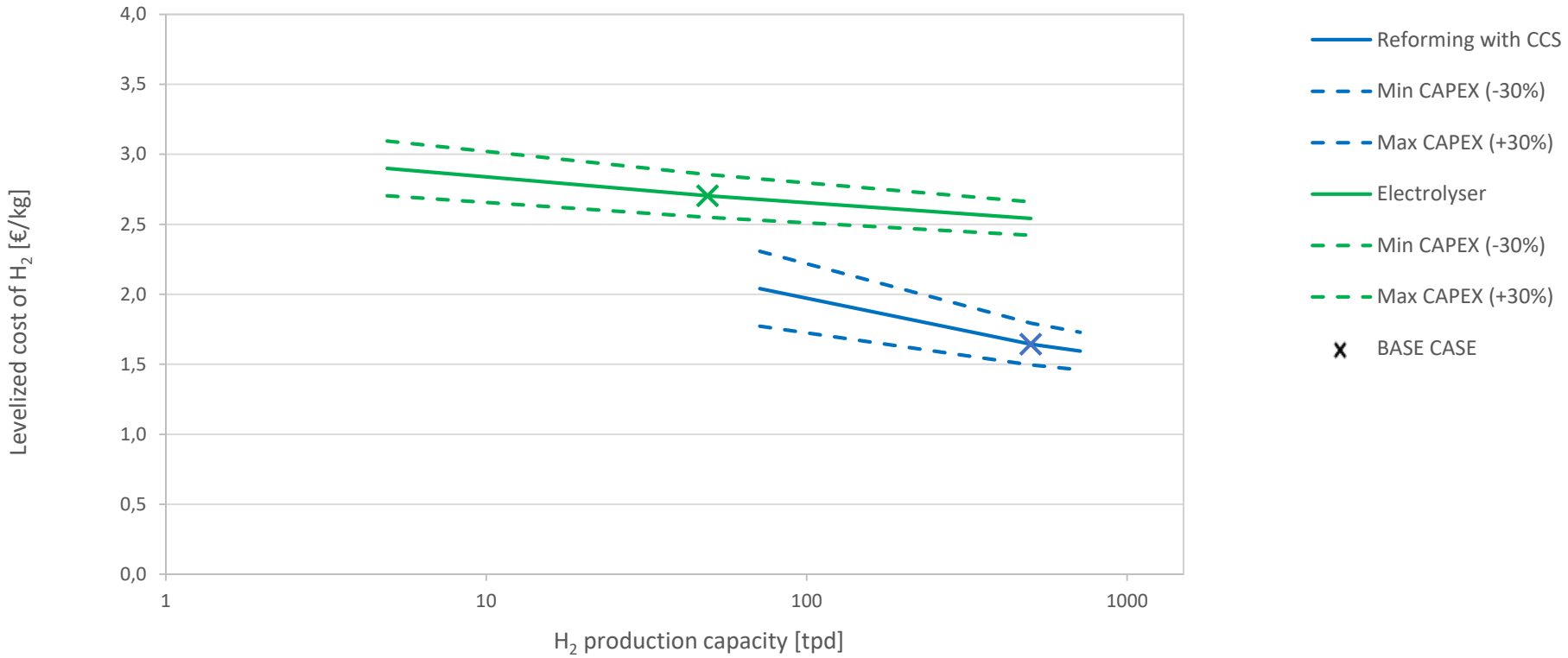
Influence of CAPEX



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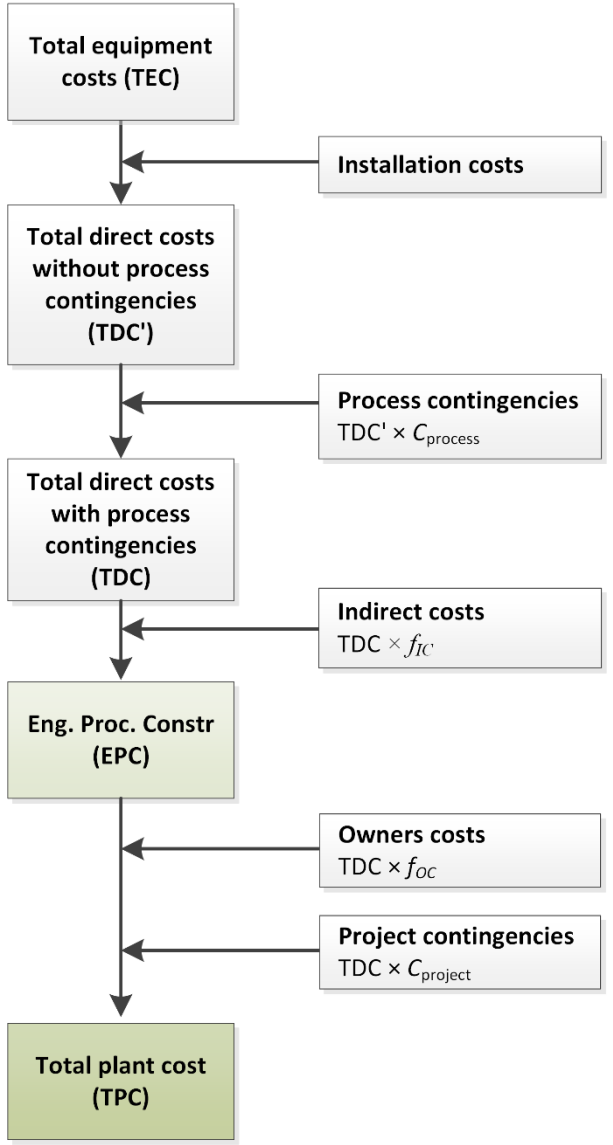
CAPEX

- Bottom-up approach
- Standard process equipment
  - Aspen Process Economic Analyzer® (APEA)
- Non-standard equipment
  - Literature
  - SINTEF in-house data
  - Input from Hyper industry partners



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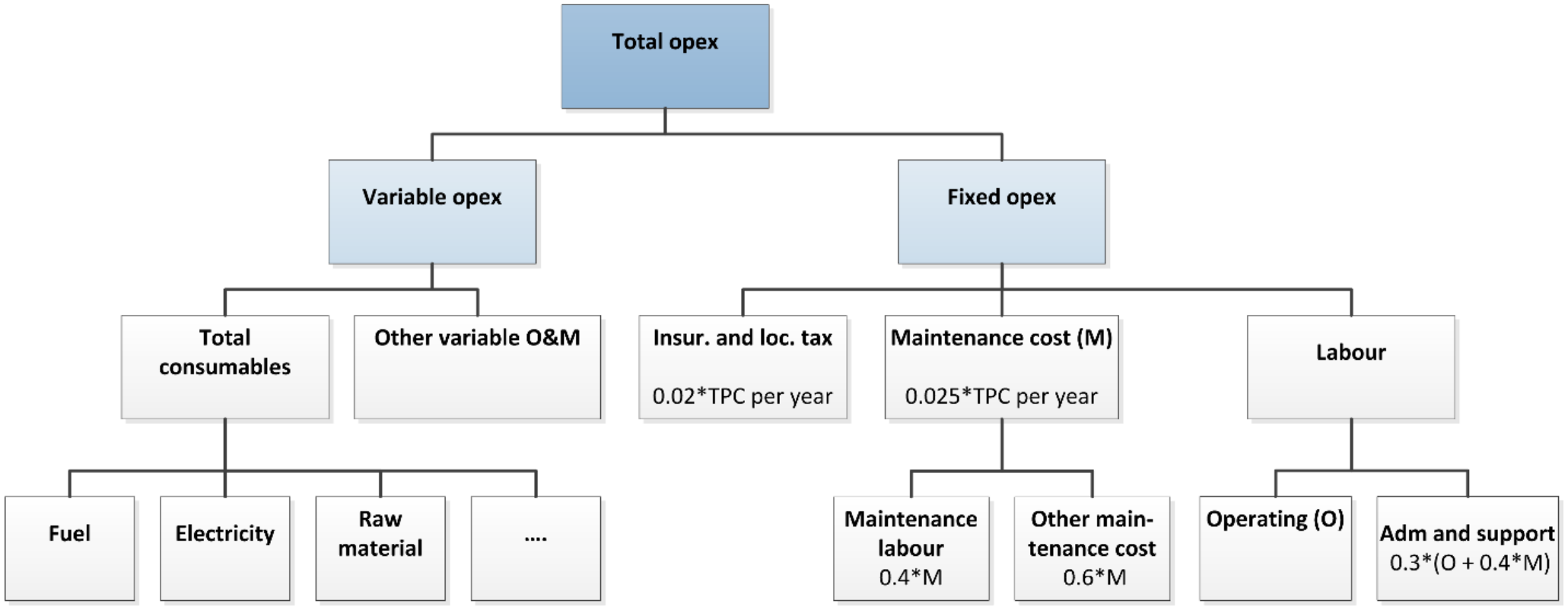
OPEX


Total opex
Variable opex
Fixed opex
Total consumables
Other variable O&M
Insur. and loc. tax
0.02*TPC per year
Maintenance cost (M)
0.025*TPC per year
Labour
Fuel
Electricity
Raw material
....
Maintenance labour
0.4*M
Other main-tenance cost
0.6*M
Operating (O)
Adm and support
0.3*(O + 0.4*M)

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Technology summary

	Natural gas reforming with CCS	Electrolysis
Maturity	+	+
Power demand	+	--
Cost	++	-
Flexibility	-	++
Large scale availability	+	-
CO_2 intensity	+	+/-